

# A descriptive study of potential effect of anterior tibial translation, femoral tunnel and anterior cruciate ligament graft inclination on clinical outcome and degenerative changes

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Received: 13 September 2016 / Accepted: 20 December 2016 / Published online: 7 January 2017  
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## Abstract

**Introduction** There is no evidence that anatomically correct anterior cruciate ligament reconstruction (ACLR) offers lower rate of degenerative changes development or that it would lead to a better outcome. The significance and understanding of the abnormal anterior tibial translation (ATT) in ACLR patients is yet to be established.

**Methods** Sixty subjects (40 patients at 5.9 years after ACLR, 20 healthy controls) underwent 3 T MRI. Quantitative cartilage T2 mapping and morphological whole organ magnetic resonance imaging score (WORMS) evaluation was performed. Self-reported questionnaires were used for subjective clinical evaluation. Correlations were calculated with the following MRI measurements; femoral tunnel inclination, ACL graft inclination, lateral and medial compartment ATT.

**Results** In the ACLR group positive correlation was found between the patellar cartilage T2 values and sagittal ACL graft inclination. In the ACLR group lateral compartment ATT showed negative correlation with ACL graft inclination and subjective clinical evaluation, and positive correlation with morphological degenerative changes. Femoral tunnel showed positive correlation with ACL graft inclination in the same plane.

**Conclusions** Increased ATT offers worse clinical outcome and increased rate of degenerative changes. Furthermore, ATT is affected by the ACL inclination. Inclination of the

drilling tunnel affects ACL graft inclination; thereby independent drilling techniques provide superior results of anatomical ACL graft positioning.

**Keywords** ACL reconstruction · Anterior tibial translation · MRI · Osteoarthritis · T2 mapping

## Introduction

Anterior cruciate ligament (ACL) is the primary restraint of anterior tibial translation (ATT) [1]. Following ACL injury, most patients have detectable excess knee laxity and may experience instability problems. The aim of the anterior cruciate ligament reconstruction (ACLR) is to reduce excess joint laxity and to restore knee kinematics [2, 3]. Previous studies have shown unsatisfactory results of the ACLR knee kinematics and have exposed an issue of long-term osteoarthritis development [4]. Recently, one of the main points of interest in ACLR has become anatomically correct reconstruction with expectations of improved outcome [2].

ACLR independent drilling techniques show a potential over transtibial technique in achieving more anatomical graft placement [2]. Furthermore, these techniques have been found to result in a more oblique femoral tunnel position than the traditional transtibial technique [2]. Oblique femoral coronal tunnel is associated with biomechanical superiority [2]. However, there is no general consensus on whether transtibial or independent techniques result in superior sagittal ACL graft obliquity [2]. Moreover, there is no evidence that anatomically correct ACLR offers lower rate of degenerative changes development or that it would lead to better clinical outcome [5].

Measurement of knee laxity is clinically important in order to make a diagnosis and to follow knee laxity before and after ACLR [1]. In clinical practice excess knee laxity can be

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determined subjectively with clinical examination or may be objectively measured with arthrometric devices. MRI has become a valuable complementary method to clinical examination in the evaluation of the degree of anterior subluxation, measured as ATT [6]. The importance of ATT as a predictor of the ACL injury has already been established, however the significance and understanding of the abnormal ATT in ACLR patients is yet to be established [7–9].

In our study ATT, femoral tunnel and ACL graft inclination measurements were undertaken in order to evaluate their effect on clinical outcome and degenerative changes. We hypothesized that all three MRI measurements would have detectable effect on clinical outcome and degenerative changes.

## Materials and methods

### Subjects

In order to obtain a greater spectrum of drilling tunnel and ACL graft positions, patients with two different ACLR techniques were included in the study. In the years 2008 to 2010 the Orthopaedic Department at our Institution gradually switched from the transtibial ACLR technique to the anteromedial portal ACLR technique. In this period two senior orthopaedic surgeons (O.Z. and K.S.) performed 107 transtibial ACLRs and 132 anteromedial portal ACLRs. Both surgeons used the same perioperative procedure and the same graft type (semitendinosus-gracilis tendon graft), all patients underwent the same rehabilitation program.

Clinical records were reviewed and 35 patients from each ACLR technique met the following study criteria. Inclusion criteria were (1) 16–45 years at ACLR, (2) body mass index (BMI) of 18.5 to 30 and (3) pre-operative sports activity of at least 4 on Tegner scale. Exclusion criteria were (1) concomitant collateral ligament disruption, (2) concomitant posterior cruciate ligament injury, (3) MRI contraindication and (4) total meniscectomy. Fifty patients were successfully contacted and written consent was obtained to participate in the study. On site two women declined the MRI examination due to pregnancy, two MRI examinations were terminated due to claustrophobia and in six patients ACL rupture was diagnosed. In the end 40 patients (17 patients were operated with the anteromedial portal technique [AM group] and 23 with the transtibial technique [TT group]) 5.9 years after the ACLR were included in the study (Table 1).

Twenty healthy volunteers were recruited for the study and were matched to the ACLR group according to age, sex, BMI and level of sports activity (Table 1). The inclusion criteria for the control group were (1) IKDC score of at least 95 and (2) no history indicative of any knee joint disorder.

### Subjective clinical evaluation

The following questionnaires were presented to the study subjects at the MRI examination; Knee injury and Osteoarthritis Outcome Score (KOOS), International Knee Documentation Committee Subjective Knee Form (IKDC), Lysholm, Tegner scale and RAND-36 Health Survey [10–14].

### Imaging protocols

MRI examinations were performed by using a 3.0 T imager (Magnetom® Trio, Siemens, Erlangen, Germany) with an 8-channel transmit-receive knee coil (Invivo, Gainesville, Florida, USA). Patients were instructed to avoid sport activities one day prior to the MRI examination and were scanned in a supine position after resting at least half an hour in order to minimize the changes of different loading conditions before the MRI examination. The same imaging protocol was used as described in our previous paper and included proton density (PD) turbo spin echo (TSE) fat saturation (FS) images in the sagittal plane (2230/29 [TR msec/TE msec], 16 cm field of view [FOV], 3 mm/1 mm [slice thickness/interslice gap], 512 x 512 matrix, 120° flip angle [FA], two signals acquired) and in the coronal plane (2540/35 [TR msec/TE msec], 15 cm FOV, 3 mm/1 mm [slice thickness/interslice gap], 384 x 384 matrix, 150° FA, two signals acquired). PD TSE images were obtained in the sagittal plane (2000/29 [TR msec/TE msec], 16 cm FOV, 3 mm/1 mm [slice thickness/interslice gap], 512 x 512 matrix, 120° FA, two signals acquired) and in the axial plane (2230/29 [TR msec/TE msec], 15 cm FOV, 3 mm/1 mm [slice thickness/interslice gap], 512 x 512 matrix, 140° FA, two signals acquired). T2 maps were obtained in the sagittal plane (1000/13.8; 27.6; 41.4; 55.2; 69.0; 82.8 [TR msec/TE msec], 16 cm FOV, 3 mm/1 mm [slice thickness/interslice gap], 384 x 384 matrix, 180° FA, 1 signal acquired) [15].

### Semi-quantitative MRI assessment

Whole Organ Magnetic Resonance Imaging Score (WORMS) system was used in the assessment of morphologic degeneration [16]. The final WORMS scores were tabulated as (1) cumulative surface feature (cartilage, marrow abnormality, subarticular cysts, bone attrition, osteophytes) scores for each compartment and (2) a total combined score for the entire knee [14]. Specific WORMS features were graded in accordance with the paper published by Peterfy et al. [16].

### Cartilage MRI relaxation time quantification

T2 maps were derived by using processing package (MapIt, Siemens Medical Solutions, Erlangen, Germany). Image analysis was performed with a Leonardo® workstation (Siemens Medical Solutions, Erlangen, Germany).

**Table 1** Group characteristics: demographics, symptoms and function of the ACLR versus control group

	Control group (n = 20)	ACLR group (n = 40)
Symptoms and function		
RAND-36 physical function (mean $\pm$ SD) *	99.0 $\pm$ 3.5	93.0 $\pm$ 11.5
RAND-36 role limitations, physical health (mean $\pm$ SD) #	100.0 $\pm$ 0	90.0 $\pm$ 23.2
RAND-36 pain (mean $\pm$ SD)	89.4 $\pm$ 14.1	80.4 $\pm$ 22.0
RAND-36 general health (mean $\pm$ SD)*	90.7 $\pm$ 7.8	79.4 $\pm$ 16.2
RAND-36 energy/fatigue (mean $\pm$ SD)*	68.8 $\pm$ 11.5	61.0 $\pm$ 12.8
RAND-36 social function (mean $\pm$ SD)	93.9 $\pm$ 12.2	90.3 $\pm$ 19.9
RAND-36 role limitations, emotional health (mean $\pm$ SD)	98.3 $\pm$ 7.4	91.7 $\pm$ 22.3
RAND-36 emotional well-being (mean $\pm$ SD)*	84.8 $\pm$ 6.9	76.3 $\pm$ 14.7
Lysholm (mean $\pm$ SD)*	99.5 $\pm$ 1.5	89.0 $\pm$ 10.4
IKDC (mean $\pm$ SD)*	98.1 $\pm$ 1.5	83.5 $\pm$ 15.4
KOOS pain (mean $\pm$ SD)*	99.6 $\pm$ 1.0	91.0 $\pm$ 13.1
KOOS symptoms (mean $\pm$ SD)*	94.8 $\pm$ 12.2	87.7 $\pm$ 14.0
KOOS activities of daily living (mean $\pm$ SD)*	99.9 $\pm$ 0.3	95.1 $\pm$ 10.4
KOOS sports and recreation (mean $\pm$ SD)	99.5 $\pm$ 2.2	80.6 $\pm$ 21.1
KOOS quality of life (mean $\pm$ SD)*	100.0 $\pm$ 0.0	70.4 $\pm$ 24.9
Demographics		
Tegner (median value)	6	6
BMI (mean $\pm$ SD)	23.7 $\pm$ 3.7	25.2 $\pm$ 3.7
Age, years (mean $\pm$ SD)	32.6 $\pm$ 6.7	34.8 $\pm$ 8.3

ACLR, anterior cruciate ligament reconstruction; BMI, body mass index; KOOS, Knee injury and Osteoarthritis Outcome Score; IKDC, International Knee Documentation Committee Subjective Knee Form.

Knee joint cartilage was manually segmented in accordance with previously reported papers and five compartments were defined: lateral femoral, medial femoral, lateral tibial, medial tibial and patella [15, 17, 18]. These were subdivided into subcompartments with regard to the menisci in a fashion of the regional subdivision used in WORMS [15, 16]. Patella was subdivided in the superior and inferior pole. In each subcompartment the zonal (deep zone - adjacent to the subchondral bone; superficial zone - adjacent to the articular surface) T2 values were obtained by undertaking an range of interest(ROI) analysis [18]. Each ROI was manually defined with multiple marker points on two consecutive midsagittal slices in each compartment. The T2 value of each ROI was expressed as the mean value of two consecutive slices measurements.

## MRI measurements

All measurements were done twice with one-month interval between the measurements. Average values of both measurements were included in the statistical analysis.

ACL graft inclination was evaluated on sagittal and coronal images as the angle between the long axis of the graft and the tibial plateau (Fig. 1a, b). Similarly, the femoral tunnel inclination was evaluated on the coronal and sagittal images as the angle between the long axis of the femoral tunnel and the tibial plateau (Fig. 1c, d).

ATT was evaluated in the lateral and medial compartment (Fig. 1e, f). To evaluate lateral compartment ATT tangential lines perpendicular to the lateral tibial plateau were drawn along the midsagittal plane of the lateral compartment at the posterior of the lateral femoral condyle and tibial plateau [6, 19]. The same approach was used in the medial compartment.

## Statistical analysis

Unpaired *t*-test was used to compare the study groups with respect to MRI measurements. Pearson correlation coefficient (R) was calculated to evaluate correlation. To assess intra-rater reliability interclass correlation coefficient (ICC) was used. Significance was set at  $P < 0.05$ . Statistical analysis was performed with SPSS v.17.0 (SPSS Inc., Chicago, Illinois, USA).

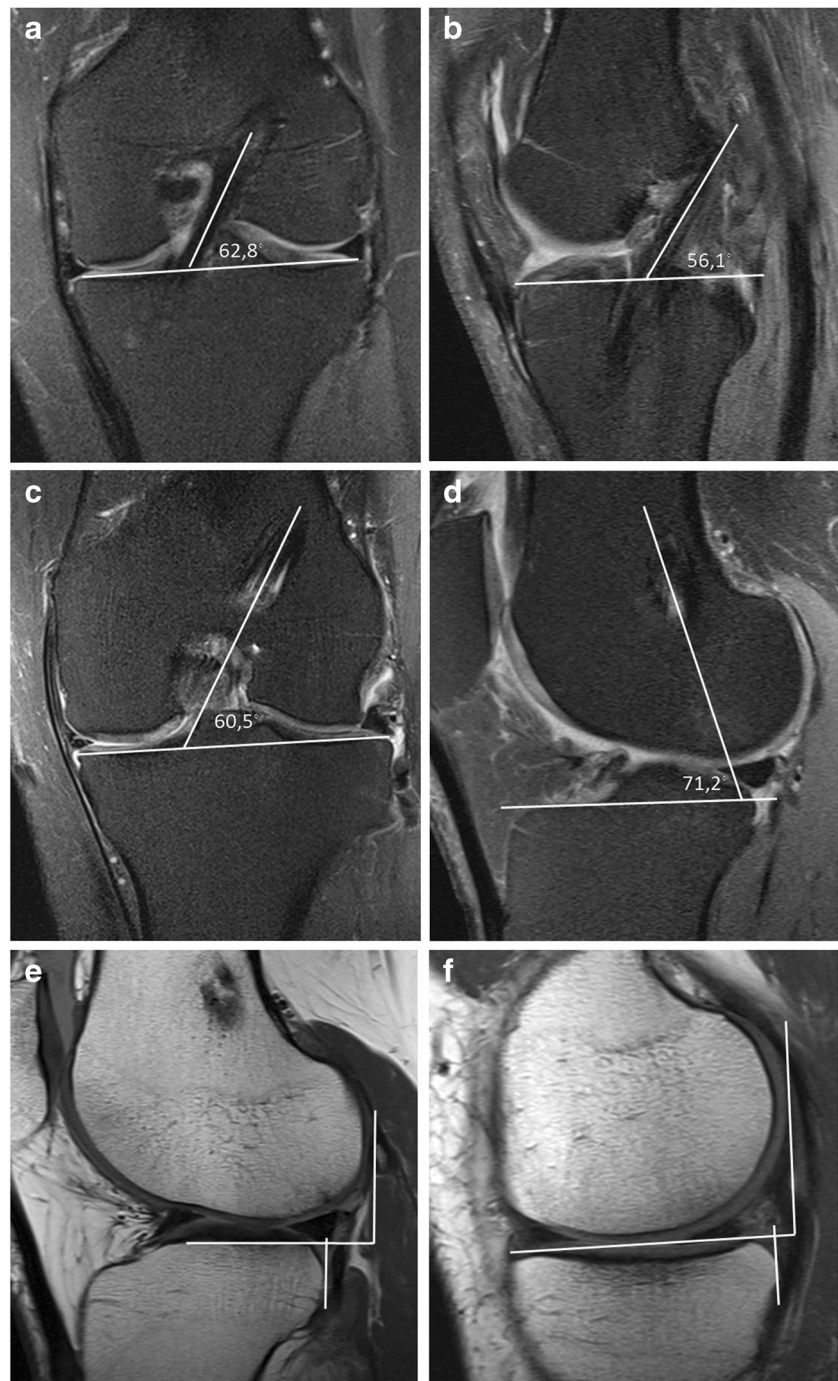
## Results

### ACLR group vs. control group

#### Femoral tunnel inclination

Mean value of the femoral tunnel inclination in the coronal plane was  $55.7^\circ \pm 9.4$  and in the sagittal plane was  $65.5^\circ \pm 10.2$ . Femoral tunnel inclination showed no

**Fig. 1** (a) coronal PD FS images showing coronal ACL graft inclination measurement, (b) sagittal PD FS images showing sagittal ACL graft inclination measurement, (c) coronal PD FS images showing coronal femoral tunnel inclination measurement, (d) sagittal PD FS images showing sagittal ACL graft inclination measurement, (e) sagittal PD images showing lateral compartment anterior tibial translation and (f) sagittal PD images showing medial compartment anterior tibial translation



correlation with subjective clinical, semi-quantitative MRI assessment and T2 values.

The intra-observer ICC of the coronal and sagittal femoral tunnel measurements were 0.93 and 0.89, respectively.

#### *ACL graft inclination*

In the coronal plane ACL graft was significantly more vertical in the ACLR group than in the control group ( $76.0^\circ \pm 8.4$  vs.  $65.2^\circ \pm 6.6$ ;  $P < 0.01$ ). In both groups coronal ACL inclination

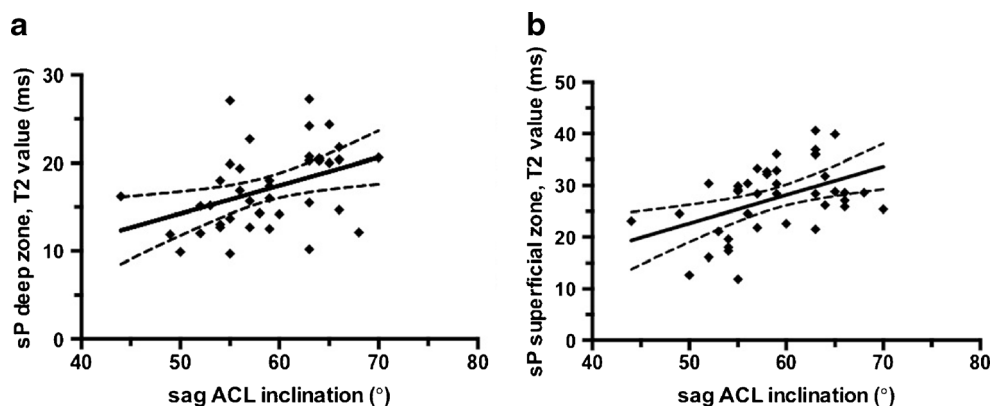
showed no correlation with subjective clinical evaluation, semi-quantitative MRI assessment or T2 values.

In the sagittal plane ACL graft was significantly more vertical in the ACLR group than in the control group ( $58.3^\circ \pm 5.9$  vs.  $52.2^\circ \pm 4.4$ ;  $P < 0.01$ ).

In both groups sagittal ACL graft inclination showed no correlation with subjective clinical evaluation and semi-quantitative MRI assessment. In the ACLR group positive correlation was found between the patellar cartilage T2 values and the sagittal ACL graft inclination; deep and superficial zones of



**Fig. 2 (a, b)** Correlations between the zonal T2 values in the superior pole of the patella subcompartment (sP) and the sagittal (sag) ACL position



the superior patellar compartment ( $R = 0.34$ ,  $P = 0.03$  and  $R = 0.47$ ,  $P < 0.01$ , respectively), and of the inferior patellar compartment ( $R = 0.33$ ,  $P = 0.03$  and  $R = 0.36$ ,  $P = 0.02$ , respectively) showed correlation with the sagittal ACL graft inclination (Fig. 2). In the control group no correlation was found between the T2 values and the sagittal ACL graft inclination.

The intra-observer ICC of the coronal and sagittal ACL graft measurements were 0.87 and 0.89, respectively.

## ATT

### Medial compartment

No difference in the mean distance for the medial compartment ATT was found between the ACLR group and control group ( $4.8 \text{ mm} \pm 2.1$  vs.  $4.0 \text{ mm} \pm 0.18$ ).

In both groups medial compartment ATT showed no correlation with clinical evaluation, cartilage T2 values and semi-quantitative MRI assessment.

### Lateral compartment

Lateral compartment ATT was significantly higher in the ACLR group than in the control group ( $8.5 \text{ mm} \pm 3.3$  vs.  $4.6 \text{ mm} \pm 2.3$ ;  $P < 0.01$ ).

ACLR group showed negative correlation between the subjective clinical evaluation and lateral compartment ATT (Table 2). In the control group no such correlation was observed.

In the ACLR group lateral compartment ATT showed positive correlation with the lateral compartment WORMS score ( $R = 0.45$ ;  $P < 0.01$ ) and with the total WORMS score ( $R = 0.33$ ;  $P = 0.04$ ) (Fig. 3). In the control group no correlation was found between the semi-quantitative MRI assessment and the lateral compartment ATT. In both groups lateral compartment ATT showed no correlation with T2 values.

The intra-observer ICC of the lateral compartment ATT and of the medial compartment ATT measurements was 0.92 and 0.89, respectively.

### Correlations of the MRI measurements

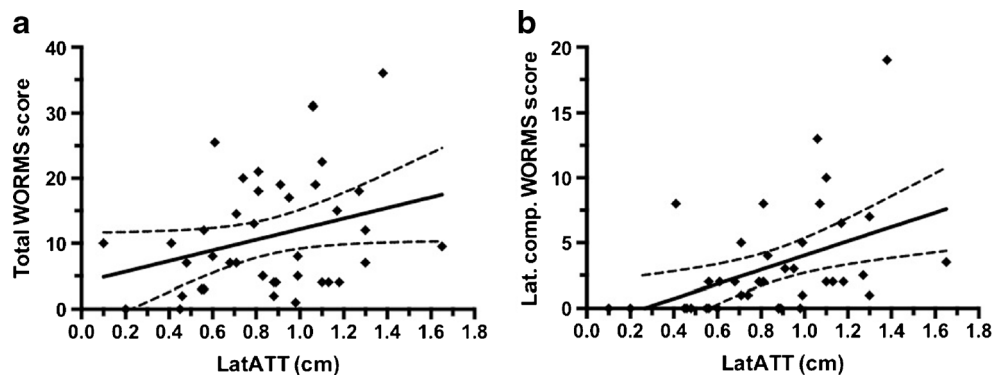
In the ACLR group negative correlation was found between the lateral compartment ATT and ACL graft inclination in the sagittal ( $R = -0.38$ ;  $P = 0.01$ ) and the coronal plane ( $R = -0.53$ ;  $P < 0.01$ ), (Fig. 4). No such correlation was found between the medial compartment ATT and ACL graft inclination. In the control group no correlation was found between ATT and ACL inclination.

**Table 2** Correlations between subjective clinical evaluation and lateral compartment anterior tibial translation in the ACLR group

	LatATT		LatATT
IKDC*	$-0.33$ ; $P = 0.04$	RAND-36	physical function
KOOS A <sup>#</sup>	$-0.27$ ; $P = 0.09$		role limitations, physical health
KOOS P <sup>#</sup>	$-0.29$ ; $P = 0.07$		pain*
KOOS Q*	$-0.33$ ; $P = 0.04$		general health*
KOOS S*	$-0.35$ ; $P = 0.02$		energy/fatigue*
KOOS Sp*	$-0.34$ ; $P = 0.03$		social function*
Lysholm <sup>#</sup>	$-0.28$ ; $P = 0.08$		role limitations, emotional health*
			emotional well-being*

LatATT, lateral compartment anterior tibial translation; KOOS, Knee injury and Osteoarthritis Outcome Score; IKDC, International Knee Documentation Committee Subjective Knee Form; <sup>#</sup>, significant at  $P < 0.10$ ; \*, significant at  $P < 0.05$ . Millimeters are unit of measurement for LatATT

**Fig. 3** (a) Correlation between total WORMS score and the lateral compartment anterior tibial translation (LatATT), (b) correlation between the lateral compartment (Lat. comp.) WORMS score and the lateral compartment ATT



In the ACLR group positive correlation was found between the coronal ACL graft inclination and coronal femoral tunnel inclination ( $R = 0.38$ ;  $P = 0.01$ ), and between the sagittal ACL graft inclination and sagittal femoral tunnel inclination ( $R = 0.38$ ;  $P = 0.01$ ). Furthermore, positive correlation between the sagittal and coronal ACL graft inclination was observed ( $R = 0.36$ ;  $P = 0.02$ ).

#### *Transtibial vs. anteromedial portal technique*

In the sagittal plane ACL graft was significantly more vertical in the TT group comparing to the AM group ( $60.4^\circ \pm 5.7$  vs.  $56.5^\circ \pm 5.0$ ,  $P = 0.03$ ). Similarly, femoral tunnel inclination in the coronal plane was more vertical in the TT group than in the AM group ( $61.1^\circ \pm 7.3$  vs.  $48.7^\circ \pm 7.4$ ,  $P < 0.01$ ). However, there was no difference between the TT and AM group in the coronal plane ACL graft inclination ( $77.2^\circ \pm 8.8$  vs.  $74.6^\circ \pm 7.4$ ), and in the sagittal plane femoral tunnel inclination ( $63.7^\circ \pm 8.6$  vs.  $67.8^\circ \pm 11.8$ ). Furthermore, there was no difference between the TT and AM group in the medial compartment ATT ( $4.1 \text{ mm} \pm 1.7$  vs.  $4.2 \text{ mm} \pm 2.0$ ), and in the lateral compartment ATT ( $8.6 \text{ mm} \pm 3.6$  vs.  $8.7 \text{ mm} \pm 3.0$ ).

No significant differences in subjective clinical evaluation or degeneration changes were observed between the groups.

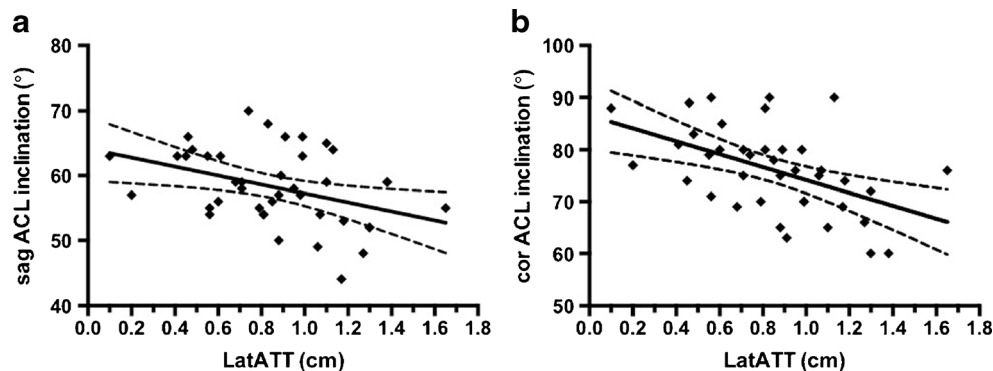
#### **Discussion**

The aim of this study was to evaluate the potential effect of ATT, femoral tunnel and ACL graft inclination on clinical outcome and degenerative changes. The most important finding of our study is that lateral compartment ATT correlates with clinical outcome and degenerative changes at mid-term follow-up.

Biomechanical studies have shown that an oblique femoral tunnel placement provides improved rotational stability compared to more vertical placement [20, 21]. Lee et al. reported that vertical femoral tunnel placement leads to worse clinical outcome when compared to more oblique placement [22]. In our study the femoral tunnel inclination showed no correlation with clinical outcome or degenerative changes.

Previous studies have shown that ACLR is unable to fully restore native ACL obliquity [23, 24]. Despite this inability, more vertically positioned grafts show good functioning and outcome [23, 24]. Similar observation was made in our study, with ACLR group showing good outcome, despite having the ACL graft placed more vertical in both planes compared to the control group. We found no correlation between the ACL position and subjective clinical evaluation. ACLR techniques have evolved with the aim of increasing graft obliquity in order to achieve anatomical graft position [25]. However, there is no evidence that restoring normal graft anatomy leads to better clinical outcome or to lower development of degenerative changes [5]. The results of our study suggest that

**Fig. 4** (a, b) Correlation between the lateral compartment anterior tibial translation (LatATT) and ACL position in the sagittal (sag) and coronal (cor) plane



placing the graft towards more anatomical position in the sagittal plane decreases patellar cartilage degeneration. However, we found no correlation between ACL position and semi-quantitative MRI assessment.

Previous studies suggest that symptoms and laxity are unrelated [26, 27]. Contrary to these results, our study showed negative correlation with knee specific and general health related questionnaires. Previous studies evaluated laxity manually or with arthrometer, hence studied dynamic laxity with knee manipulation. This is an important difference with our study, since passive laxity assessed in our study, may demonstrate different underlying pathological mechanisms. We propose, that in knee manipulation some degree of reflex muscle tone may persist due to muscle stretching and activation of proprioceptors, thus masking the actual passive laxity. Furthermore, ACLR knees can have fixed anterior tibial subluxation, thereby exhibiting little or no increase in total sagittal motion, thus making dynamic evaluation of femorotibial relationship less reliable [7]. On MRI patient's muscles are fully relaxed, revealing the true femorotibial relationship. Furthermore, we found negative correlation between the lateral compartment ATT and ACL graft inclination; patients with more oblique grafts showed higher degrees of lateral compartment ATT. This finding was unexpected and an explanation is less obvious. This new observation warrants further consideration.

Our explanation for the lateral compartment ATT and ACL graft inclination relationship is based on the differences of surgical techniques. Almekinders et al. speculated that tightening of the posterior-restraining structures may cause the fixed subluxation and that such a process can be initiated by the ACLR itself [7]. We propose, that an attempt to position the femoral footprint in an anatomical position may pose greater trauma to the posterior structures, thereby causing postsurgical fibrosis to a greater degree that can be manifested as fixed anterior subluxation.

Another possible explanation for the negative lateral compartment ATT and ACL graft inclination correlation may be different graft remodelling in relation to graft angulation. Ochi et al. showed in the native ACL that different biomechanics in isolated PCL insufficiency could induce morphological changes in native ACL collagen fibrils [28]. It is known that after implementation ACL graft undergoes different stages of healing and remodelling [29]. We propose that graft remodelling may be altered with different loading distribution due to graft inclination; thereby different load distribution may impact graft healing and potential graft tightening with fixed ATT.

Fixed subluxation will likely prevent improved tibiofemoral kinematics even in the face of reduced ATT [7]. This may explain, at least in part, why ACLR may not reduce the incidence of osteoarthritis [6, 30]. Previous studies showed that the abnormal patterns of ATT have increased cartilage breakdown in the medial compartment as well as patella [9, 31]. In our study no correlation was found between the T2 values and ATT. However, positive correlation was found between the semi-

quantative MRI assessment and lateral compartment ATT. Thus, suggesting a link between abnormal kinematics and osteoarthritis development in ACLR knees. Interestingly, we found correlation with total WORMS score and the lateral compartment WORMS score, however none was found with the medial compartment or patellofemoral compartment WORMS score. Furthermore, no correlation was found between medial compartment ATT and degenerative changes. This may be explained by the fact that ACLR patients have abnormal tibiofemoral kinematics especially in the lateral compartment [30].

We found no previous studies evaluating the relationship between the ACL graft and femoral tunnel inclination. We have shown that the inclination of the femoral tunnel strongly affects the ACL graft inclination in the same plane. Furthermore, we found positive correlation between sagittal and coronal ACL graft inclination. Our results suggest that the independent drilling techniques provide better results in restoring native ACL obliqueness by adjusting the femoral tunnel inclination.

The following limitations need to be considered. No pre-operative MRI evaluation was performed, thus direct longitudinal MRI evaluation of degeneration changes could not have been evaluated. Postoperative MRI evaluation and clinical outcomes have to be interpreted with caution as the MRI degenerative changes could have been present prior to the surgery, however our research was focused on existing correlations and not on absolute values. Clinical evaluation with only self-reported questionnaires was performed without objective clinical evaluation or evaluation of clinical knee laxity.

In conclusion, we found no effect of femoral tunnel inclination on clinical outcome and degeneration changes. Increased ATT offers worse clinical outcome and increased rate of degenerative changes. Furthermore, ATT is affected by the ACL inclination. Inclination of the drilling tunnels affect ACL graft inclination; thereby independent drilling techniques provide superior results of anatomical ACL graft positioning.

**Acknowledgements** We acknowledge radiological technicians at our institution for direct technical assistance, including help with patients and equipment. We acknowledge M. Števanac for assistance with statistical analysis. This research was partially funded by the Young Researchers Grant awarded by the European Society of Musculoskeletal Radiology.

**Compliance with Ethical Standards** The National Medical Ethics Committee approved the study (date of issue: 19.8.2014, registration number: 135/08/14) and informed consent was obtained from the subjects after the nature of the study had been fully explained.

**Conflict of Interest** None.

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